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METHOD FOR ESTIMATING POWER AND FUEL CONSUMPTION OF NORMAL COMPRESSION AVIATION ENGINES IN FLIGHT AT VARIOUS ALTITUDES

(POWER PLANT SECTION REPORT)

▽

Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio
September 1, 1921

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CERTIFICATE.—By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

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CHANGES No. 4.

WAR DEPARTMENT, AIR SERVICE, *August 15, 1922.*

Page 5, Table II, sections A and B, and page 6, Table IIa, inclusive, Air Service Information Circular, Volume IV, No. 317, and Changes No. 3, Air Service Information Circular, Volume IV, No. 317, "Method for Estimating Power and Fuel Consumption of Normal Compression Aviation Engines in Flight at Various Altitudes," are changed, by direction of the Chief of Air Service, in accordance with recommendation of the Engineering Division contained in a letter dated July 7, 1922, as follows:

Page 5, Table II, sections A and B, substitute the following:

TABLE II.—*Estimated full-throttle horsepower at actual revolutions per minute at sea level and various altitudes.*[1]

SECTION A.—NORMAL COMPRESSION RATIOS APPROXIMATELY 5-5.5:1.

Engine and class of service.	Model.	Normal revolutions per minute.	Total weight dry, pounds.	Horsepower at actual revolutions per minute.[2] Sea level.	5,000 feet.	10,000 feet.	15,000 feet.	20,000 feet.	25,000 feet.
Training:									
Aeromarine	U-8-D	1,600	560	180	148	117	90	64	39
Curtiss	OX-5	1,400	385	90	74	59	45	32	20
Curtiss	C-6	1,750	450	160	132	104	80	57	35
Lawrance	J-1	1,650	447	180	148	117	90	64	39
Le Rhone	C	1,200	260	[3] 80	66	52	40	29	17
Le Rhone	Jb	1,200	320	[3] 120	99	78	60	43	26
Liberty [4]	"6"	1,700	635	200	165	130	100	72	44
Packard	825	1,450	555	180	148	117	90	64	39
Rausie	E-6	1,650	550	160	132	104	80	57	35
Wright-Hispano	E-2	1,700	475	180	148	117	90	64	39
Wright-Hispano	I	1,700	470	180	148	117	90	64	39
Alert:									
Aeromarine	U-8-D	2,000	560	200	165	130	100	72	44
Lawrance	J-1	1,800	447	[5] 200	165	130	100	72	44
Le Rhone	R	1,350	380	160	132	104	80	57	35
Packard	825	2,000	555	225	186	147	113	81	49
Wright-Hispano	E-2	2,000	475	210	173	137	105	75	46
Pursuit:									
Almen	Barrel	2,000	725	[6] 375	309	245	188	134	82
Curtiss	CD-12	2,000	705	375	309	245	188	134	82
Packard	1237	1,800	740	[6] 325	268	212	163	116	71
Wright-Hispano	H	1,800	635	310	256	202	156	111	68
Wright-Hispano	H-3	1,800	620	315	260	205	158	113	69
Wright-Hispano	H-3	2,000	620	350	289	228	176	125	76
Wright	Radial	1,650	[5] 885	[5] 350	289	228	176	125	76
Observation and bombardment:									
Liberty	"12"	1,700	[7] 845	400	330	261	201	143	87
Liberty [8]	"12"	1,700	1,010	400	400	400	400	400	333
McCook	W-1	1,700	1,815	700	578	456	351	250	153
McCook	W-2	1,400	[5] 2,400	[5] 1,000	825	652	502	358	218
Packard	2025	1,700	1,170	520	429	339	261	186	113
Miscellaneous:									
Lawrance	"L" series	1,700	160	55	45	36	28	20	12
Lawrance	Torpedo	1,800	155	60	49	39	30	21	13

[1] Add 10 per cent to power output in making computations for cooling systems. The performance estimates are based on actual tests except in instances where reference is made to footnotes 3 and 5. In most cases the estimates are lower than the test results to allow for variation between engines, atmospheric variations, etc.
[2] Allowing for drop in engine propeller speed based on average drop observed on numerous tests of Liberty and Wright-Hispano engines.
[3] Rated power. Actual developed power not known.
[4] Equipped with magneto ignition.
[5] Estimated. (Engines under construction; in most cases no test data or weights are available.)
[6] Power output obtained from report by Packard Motor Car Co. No engines of this type (with low compression) are planned for production.
[7] Weight is with Zenith U. S. 52 carburetors. With inverted carburetors weight is 860 pounds.
[8] Equipped with General Electric supercharger. Power output assumed constant to 20,000 feet and then to decrease with decrease in density.

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Table II.—*Estimated full-throttle horsepower at actual revolutions per minute at sea level and various altitudes*—Contd.

SECTION B.—HIGH-COMPRESSION RATIO OF 6½:1.

Engine and class of service.	Model.	Normal revolutions per minute.	Total weight dry, pounds.	Horsepower, unblended gasoline.		Horsepower with doped fuel.[9]					
				Sea level.	5,000 feet.[10]	Sea level.	5,000 feet.	10,000 feet.	15,000 feet.	20,000 feet.	25,000 feet.
Training:											
Aeromarine	U-8-D	1,600	560	147	147	195	161	127	98	70	43
Curtiss	C-6	1,750	450	132	132	175	144	114	88	63	38
Lawrance	J-1	1,650	447	147	147	195	161	127	98	70	43
Liberty	"6"	1,700	635	162	162	215	177	140	108	77	47
Packard	825	1,450	555	147	147	195	161	127	98	70	43
Wright-Hispano	E-2	1,700	475	147	147	195	161	127	98	70	43
Alert:											
Aeromarine	U-8-D	2,000	560	162	162	215	177	140	108	77	47
Lawrance	J-1	1,800	447	162	162	215	177	140	108	77	47
Packard	825	2,000	555	180	180	240	198	157	121	86	52
Wright-Hispano	E-2	2,000	475	169	169	225	186	147	113	81	49
Pursuit:											
Almen	Barrel	2,000	725	305	305	405	334	264	203	145	88
Curtiss	CD-12	2,000	705	305	305	405	334	264	203	145	88
Packard	1237	1,800	740	263	263	350	289	228	176	125	76
Wright-Hispano[11]	H-3	1,800	620	256	256	340	280	221	171	122	74
Wright-Hispano[11]	H-3	2,000	620	282	282	375	309	245	188	134	82
Wright	Radial	1,650	[12] 885	286	286	380	313	248	191	136	83
Observation and bombardment:											
Liberty[11]	"12"	1,700	845	338	338	450	371	294	226	161	98
McCook	W-1	1,700	1,815	568	568	755	623	492	379	270	165
McCook	W-2	1,400	[12] 2,400	812	812	1,080	891	704	542	387	235
Packard	2,025	1,700	1,170	423	423	562	464	366	282	201	123

[9] Allowing for drop in engine-propeller speed based on average drop observed on numerous tests of Liberty and Wright-Hispano engines with normal compression ratios. While tests show that the drop is not quite as great for the high-compression ratio, the absolute difference is small enough to be disregarded for the sake of simplicity.

[10] This horsepower is maintained (by throttling) to 7,000 feet. Above 7,000 feet, values are the same as for operation with doped fuel.

[11] Increase of sea-level horsepower with 6½:1 compression ratio obtained from actual tests of high-compression engines compared with output with 5–5½:1 compression ratios. For the other engines the sea-level horsepower (using doped fuel) was estimated to be 8 per cent greater than the sea-level horsepower with 5–5½:1 compression ratios.

[12] Estimated.

(*C. A. S. I. C. 4.*)

Page 6, Table IIa, substitute the following:

Table IIA.—*Estimated full-throttle fuel and oil consumption in pounds per hour at sea level and various altitudes for both normal and high-compression ratios.*[1]

Engine and class of service.	Model.	Normal revolutions per minute.	Fuel consumption, unblended gasoline.[2]		Hourly fuel consumption in pounds.[1]						Oil consumed, pounds per hour.
			Sea level.	5,000 feet.	Sea level.	5,000 feet.	10,000 feet.	15,000 feet.	20,000 feet.	25,000 feet.	
Training:											
Aeromarine	U-8-D	1,600	76	76	97	83	68	56	50	48	7.2
Curtiss	OX-5	1,400	(3)	(3)	49	42	34	28	25	24	3.6
Curtiss	C-6	1,750	68	68	86	74	61	50	44	43	6.4
Lawrance	J-1	1,650	81	81	103	88	73	60	53	51	10.8
Le Rhone	C	1,200	(3)	(3)	64	55	45	37	33	32	6.4
Le Rhone	Jb	1,200	(3)	(3)	96	82	68	56	49	48	9.6
Liberty	"6"	1,700	85	85	108	92	76	63	56	54	8.0
Packard	825	1,450	76	76	97	83	68	56	50	48	7.2
Rausie	E-6	1,650	(3)	(3)	86	74	61	50	44	43	6.4
Wright-Hispano	E-2	1,700	76	76	97	83	68	56	50	48	7.2
Wright-Hispano	I	1,700	(3)	(3)	97	83	68	56	50	48	7.2
Alert:											
Aeromarine	U-8-D	2,000	85	85	108	92	76	63	56	54	8.0
Lawrance	J-1	1,800	90	90	114	98	80	66	59	57	12.0
Le Rhone	R	1,350	(3)	(3)	128	109	90	74	66	64	12.8
Packard	825	2,000	96	96	122	104	86	71	63	61	9.0
Wright-Hispano	E-2	2,000	89	89	113	97	80	66	58	56	8.4
Pursuit:											
Almen	Barrel	2,000	160	160	203	173	143	118	104	101	22.5
Curtiss	CD-12	2,000	160	160	203	173	143	118	104	101	15.0
Packard	1237	1,800	138	138	175	150	123	102	90	87	13.0
Wright-Hispano	H	1,800	(3)	(3)	167	143	118	97	86	83	12.4
Wright-Hispano	H-3	1,800	134	134	170	145	120	99	87	84	12.6
Wright-Hispano	H-3	2,000	149	149	189	162	133	110	97	94	14.0
Wright	Radial	1,650	158	158	200	171	141	116	103	99	21.0
Observation and bombardment:											
Liberty	"12"	1,700	170	170	216	185	152	125	111	107	16.0
Liberty (supercharged)	"12"	1,700	(4)	(4)	216	216	216	216	216	200	16.0
McCook	W-1	1,700	298	298	378	323	266	219	194	188	28.0
McCook	W-2	1,400	426	426	540	462	380	313	278	268	40.0
Packard	2025	1,700	221	221	281	240	198	163	145	140	20.8
Miscellaneous:											
Lawrance	"L" series	1,700	(3)	(3)	31	27	22	18	16	15	3.3
Lawrance	Torpedo	1,800	(3)	(3)	34	29	24	20	18	17	3.6

[1] The hourly fuel consumption for both normal and high-compression ratios is assumed to be the same at a given speed, since no changes in carburetor setting are contemplated or are generally necessary. However, with the high ratios "doped" fuel must be used.

[2] This data applies only to high-compression engines which have to be throttled at sea level and up to 7,000 feet to avoid detonation. This fuel consumption is maintained to 7,000 feet. Above 7,000 feet, values are the same as for operation with doped fuel.

[3] These engines will not be equipped with high-compression ratio.

[4] The supercharged Liberty does not have to be run throttled, as explained in footnote 3.

(*C. A. S. I. C. 4.*)

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METHOD FOR ESTIMATING POWER AND FUEL CONSUMPTION OF NORMAL COMPRESSION AVIATION ENGINES IN FLIGHT AT VARIOUS ALTITUDES.

OBJECT.

The object of this report is to furnish a standard method for estimating performance of normal compression engines in flight at various altitudes.

SUMMARY OF RESULTS.

Figures for estimating the altitude performance of normal compression engines are given in Table I.

In the case of the normal engines it is necessary to know the sea-level horsepower of the engine at the normal operating speed, and the hourly fuel consumption at that speed. The table gives values for altitudes other than sea level in per cent of the sea-level quantities.

In Table II the performance data for a number of representative engines have been computed, using the figures given in Table I.

A report on the methods used in estimating the performance at altitudes of overdimensioned and overcompressed engines is in preparation and will be issued as a supplement to this report, when completed

METHOD OF COMPUTATION.

At the present time the only reliable data available on engine performance at various altitudes are those which have been obtained on a few airplane engines in the altitude chamber at the Bureau of Standards. Any estimate of altitude performance must be based on these results, since no others are available. The results obtained in the altitude chamber differ from conditions of actual flight in the following respects:

(*a*) The engine speed has been held constant with varying altitude.

(*b*) The atmospheric conditions actually existing at various altitudes have not been accurately duplicated.

(*c*) The engine is run under conditions more favorable to good performance than is the case in actual service.

In estimating service performance, therefore, allowance must be made for the above discrepancies.

The performance estimates given herewith are based on results of Bureau of Standards altitude chamber tests on three representative service engines and on a large number of flights tests with different engine-propeller-airplane combinations. The method of compiling these data and of making allowance for the difference between altitude chamber results and actual service is described hereinafter.

Table III is a summary of the power results of the altitude chamber tests of the Liberty 12, the Hispano-Suiza model "H," and the Hispano-Suiza model "E" engines. The figures given are the average of the results on these engines, each operating at two different speeds. These data do not allow for the drop in speed of the engine-propeller unit, but merely represent the average test block results where the speed was held constant and other conditions of the test were controlled carefully.

Table IV: In order to estimate the power output in flight, it is not enough merely to correct for changes due to decreasing density, but some allowance must be made for drop in speed of the engine-propeller unit. The figures given in this table represent the average drop in speed with altitude of 13 engine-propeller-airplane units in flight, consisting of eight Liberty 12, four Hispano-Suiza model "H," and one Hispano-Suiza model "E" engines.

Table V: This table gives the variation in horsepower with altitude, taking into account the drop in speed of the engine-propeller unit with increasing altitude. The data of Table V are obtained by multiplying the data of Table III by those of Table IV at each altitude. For instance, the horsepower at 15,000 feet, at constant speed, is 53.7 per cent of the sea-level horsepower (Table III). At 15,000 feet the speed of the engine-propeller unit is 93.4 per cent of its speed at sea level (Table IV). The product of 0.537 and 0.934 is 0.502, and the horsepower, therefore, of an engine mounted in an airplane at 15,000 feet is assumed to be 50.2 per cent of the sea-level data (Table V). This computation is made on the assumption that the horsepower is directly proportional to the engine speed. Such an assumption is allowable, as the actual difference in speed is small. The error is within the limits of accuracy of those performance estimates.

The power output variation as given in this table forms the basis for the estimate of hourly fuel consumption.

Table VI: The brake specific fuel consumption increases with altitude, due largely to the decrease in mechanical efficiency. This table shows the average variation in the brake specific fuel consumption with altitude obtained on tests run in the altitude chamber of the Bureau of Standards on the model "H" Hispano-Suiza and the 12-cylinder Liberty engines each operating at two speeds. The original data from which the figures for each altitude were obtained can be found in Engineering Division Reports, Serials Nos. 1232 and 1233.

Table VII: The hourly fuel consumption at various altitudes is expressed in this table as a percentage of the quantity of fuel consumed in one hour at sea level. The data are obtained by multiplying together the values tabulated in Tables V and VI at any given altitude. For instance, the horsepower at 20,000 feet, allowing for drop in speed, is 35.8 per cent of the sea-level horsepower (Table V). The specific fuel consumption at this altitude is 144.1 per cent of the sea-level consumption (Table VI). The product of 0.358 and 1.441 is 0.514, and the hourly fuel consumption at 20,000 feet is, therefore, taken to be 51.4 per cent of the hourly fuel consumption at sea level.

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Referring to page 3, item (*a*) has been allowed for by correcting for the variation in speed as already explained. The difference in atmospheric conditions between the altitude chamber tests and actual flight, item (*b*), consists largely in differences in temperature at the higher altitude, the temperatures in the chamber averaging higher than actual temperatures at the corresponding altitudes. Since no reliable method for correcting for temperature is available, this difference can not be allowed for in the tables. Indications are, however, that the effect on engine performance of these temperature differences is so small as to be well within the limits of accuracy of these tables.

In regard to item (*c*), it is believed that the rate of change of power and fuel consumption with altitude is not greatly different in the altitude laboratory and in flight, provided the carburetor altitude control is properly handled in both cases. It is sufficient, therefore, to allow for the more favorable laboratory conditions in the absolute values of the power and fuel consumption at sea level. The following allowances are therefore recommended:

(*a*) *Horsepower.*—Where test results are available on a number of engines of the type in question, the average of these results should be taken as the sea-level value to be substituted in the tables. Where a laboratory test on one engine only is available, the sea-level horsepower should be reduced by 5 per cent to allow for the less favorable flight conditions and the variation between different engines of the same model.

(*b*) *Fuel consumption.*—Experience has shown that the fuel consumption obtained on test is always lower than that in flight. The following values are therefore recommended as representing average specific fuel consumption in flight at sea level:

	Pound per horsepower hour.
Water-cooled engines	0.54
Air-cooled radials	.57
Rotary engines	.80

(*c*) The oil consumption of different engines, even of the same model, varies enormously. In estimating oil consumption, the maximum probable consumption should be used. Rather than depend on laboratory tests of a limited number of engines, the following values are recommended for normal engines:

	Pound per horsepower hour.
Vertical and "V" engines	0.04
Radial engine	.07
Rotary engines	.08

The Air Service plans to reject or re-overhaul engines which exceed the above oil consumptions. Since data on oil consumption at various altitudes are lacking, it should be assumed that the hourly oil consumption of all engines is the same at all altitudes as at sea level.

INSTRUCTIONS FOR ESTIMATING POWER AND FUEL CONSUMPTION.

For normal engines.—Use columns A and B of Table I. Determine the horsepower at sea level. The horsepower at altitude will bear the same relation to the sea-level horsepower as the percentages in column A. Determine the hourly fuel consumption at sea level, which is the product of the sea-level horsepower and the specific brake fuel consumption at sea level. The hourly fuel consumption at other altitudes will bear the same relation to the sea-level consumption as the percentages in column B.

For instance, given that the output at sea level at the normal speed of the Liberty engine is 400 horsepower and its brake specific fuel consumption is 0.540 pound per horsepower hour and oil consumption 0.04 pound per horsepower hour, to find the power output and hourly fuel and oil consumption at 15,000 feet.

From column A, the horsepower at 15,000 feet is 50.2 per cent of the sea-level horsepower or $400 \times 0.502 = 200.8$ horsepower.

The hourly fuel consumption at sea level would be $400 \times 0.540 = 216$ pounds.

From column B, the hourly fuel consumption at 15,000 feet is 58 per cent of the sea-level consumption, or $216 \times 0.58 = 125.3$ pounds.

The oil consumption is 400×0.04, or 16 pounds per hour for all altitudes.

The same method is followed for other altitudes.

TABLE I.—*Per cent variation in performance at altitude of normal engines, allowing for change in speed of engine-propeller unit.*

Altitude.	Normal engines.	
	A Horsepower.[1]	B Hourly fuel consumption.[2]
Sea level	100.0	100.0
5,000 feet	82.5	85.5
10,000 feet	65.2	70.4
15,000 feet	50.2	58.0
20,000 feet	35.8	51.4
25,000 feet	21.8	49.7

[1] See Table V. [2] See Table VII.

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TABLE II.—*Estimated full-throttle horsepower at actual revolutions per minute at sea level and various altitudes.*[1]

SECTION A.—NORMAL COMPRESSION RATIOS APPROXIMATELY 5–5½ : 1.

Engine.	Model.	Normal revolutions per minute.	Total weight dry, pounds.	Horsepower at actual revolutions per minute.[2] Sea level.	5,000 feet.	10,000 feet.	15,000 feet.	20,000 feet.	25,000 feet.
Liberty [3]	6	1,700	635	200	165	130	100	72	44
Liberty	12	1,700	[4] 845	400	330	261	201	143	87
Liberty [5]	12	1,700	1,010	400	400	400	400	400	333
Packard	825	1,800	555	215	177	140	108	77	47
Packard [6]	1237	1,800	740	325	268	212	163	116	71
Packard	2025	1,800	1,170	540	446	352	271	193	118
Wright Hispano	I	1,450	470	154	127	101	77	55	34
Wright Hispano [7]	E-2	1,800	475	190	157	124	95	68	41
Wright Hispano [8]	E-2	2,000	475	210	173	137	105	75	46
Wright Hispano	H	1,800	635	310	256	202	156	111	68
Wright Hispano	H-3	2,000	620	350	289	228	176	125	76
Wright	Radial	1,800	[9] 885	[9] 350	289	228	176	125	76
Lawrance	3 cyl	1,600	150	50	41	33	25	18	11
Lawrance	R-1	1,600	400	140	116	91	70	50	31
Lawrance	J-1	1,800	[9] 435	[9] 200	165	130	100	72	44
Le Rhone	C	1,200	260	[10] 80	66	52	40	29	17
Le Rhone	J-b	1,200	320	[10] 120	99	78	60	43	26
Le Rhone	R	1,350	380	[10] 180	148	117	90	64	39
Curtiss	OX-5	1,400	385	[10] 90	74	59	45	32	20
Curtiss	C-6	1,750	450	160	132	104	80	57	35
Curtiss (direct)	C-12	2,000	705	375	309	245	188	134	82
Rausie	E-6	1,650	550	160	132	104	80	57	35
Aeromarine	U-8-D	1,600	560	170	140	111	85	61	37
Almen	Barrel	2,000	[9] 700	[9] 375	309	245	188	134	82
McCook	W-1	1,700	1,700	700	578	456	351	250	153
McCook	W-2	1,400	[9] 2,400	[9] 1,000	825	652	502	358	218

[1] Add 10 per cent to power output in making computations for cooling systems. The performance estimates are based on actual tests except in instances where reference is made to footnotes 9 and 10. In most cases, the estimates are lower than the test results to allow for variation between engines, atmospheric variations, etc.

[2] Allowing for drop in engine propeller speed based on average drop observed on numerous tests of Liberty and Wright Hispano engines.

[3] Equipped with magneto ignition.

[4] Weight is with Zenith U. S. 52 carburetors. With inverted carburetors weight is 860 pounds.

[5] Equipped with General Electric supercharger. Power output assumed constant to 20,000 feet and then to decrease with decrease in density.

[6] Power output obtained from report by Packard Motor Car Co.

[7] Training.

[8] Alert.

[9] Estimated. (Engines under construction: in most cases no test data or weights are available.)

[10] Rated power. Actual developed power not known.

SECTION B.—HIGH COMPRESSION RATIO OF 6½ : 1.

Engine.	Model.	Normal revolutions per minute.	Total weight dry, pounds.	Horsepower, unblended gasoline. Sealevel.	5,000 feet.[12]	Horsepower with doped fuel.[11] Sealevel.	5,000 feet.	10,000 feet.	15,000 feet.	20,000 feet.	25,000 feet.
Liberty	6	1,700	635	162	162	215	177	140	108	77	47
Liberty [13]	12	1,700	845	338	338	450	371	294	226	161	98
Packard	825	1,800	555	177	177	235	194	153	118	84	51
Packard	1237	1,800	740	263	263	350	289	228	176	125	76
Packard	2025	1,800	1,170	440	440	585	483	381	294	209	128
Wright Hispano	I	1,450	470	124	124	165	136	108	83	59	36
Wright Hispano	E-2	1,800	475	154	154	205	169	134	103	73	45
Wright Hispano	E-2	2,000	475	169	169	225	186	147	113	81	49
Wright Hispano [13]	H	1,800	635	252	252	335	276	218	168	120	73
Wright Hispano [13]	H-3	2,000	620	282	282	375	309	245	188	134	82
Wright	Radial	1,800	[14] 885	286	286	380	313	248	191	136	83
Lawrance	3 cyl	1,600	150	41	41	55	45	36	28	20	12
Lawrance	R-1	1,600	400	113	113	150	124	98	75	54	33
Lawrance	J-1	1,800	[14] 435	162	162	215	177	140	108	77	47
Le Rhone	C	1,200	260	64	64	[15] 85	70	55	43	30	19
Le Rhone	J-b	1,200	320	98	98	[15] 130	107	85	65	47	28
Le Rhone	R	1,350	380	147	147	[15] 195	161	127	98	70	43
Curtiss	OX-5	1,400	385	71	71	95	78	62	48	34	21
Curtiss	C-6	1,750	450	132	132	175	144	114	88	63	38
Curtiss (direct)	C-12	2,000	705	305	305	405	334	264	203	145	88
Rausie	E-6	1,650	550	132	132	175	144	114	88	63	38
Aeromarine	U-8-D	1,600	560	139	139	185	153	121	93	66	40
Almen	Barrel	2,000	[14] 700	305	305	405	334	264	203	145	88
McCook	W-1	1,700	1,700	568	568	755	623	492	379	270	165
McCook	W-2	1,400	[14] 2,400	812	812	1,080	891	704	542	387	235

[11] Allowing for drop in engine-propeller speed based on average drop observed on numerous tests of Liberty and Wright Hispano engines with normal compression ratios. While tests show that the drop is not quite as great for the high-compression ratio, the absolute difference is small enough to be disregarded for the sake of simplicity.

[12] This horsepower is maintained (by throttling) to 7,000 feet. Above 7,000 feet values are the same as for operation with doped fuel.

[13] Increase of sea-level horsepower with 6½ : 1 compression ratio obtained from actual tests of high-compression engines compared with output with 5–5½ : 1 compression ratios. For the other engines the sea-level horsepower (using doped fuel) was estimated to be 8 per cent greater than the sea-level horsepower with 5–5½ : 1 compression ratios.

[14] Estimated.

[15] Very questionable, since data on high-compression rotaries are lacking.

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Table IIa.—*Estimated full-throttle fuel and oil consumption in pounds per hour at sea level and various altitudes for both normal and high compression ratios.*[1]

Engine.	Model.	Normal revolutions per minute.	Fuel consumption, unblended gasoline.[2]		Hourly fuel consumption in pounds.[1]						Oil consumed, pounds per hour.
			Sea level.	5,000 feet.	Sea level.	5,000 feet.	10,000 feet.	15,000 feet.	20,000 feet.	25,000 feet.	
Liberty	6	1,700	85	85	108	92	76	63	56	54	8.0
Liberty	12	1,700	170	170	216	185	152	125	111	107	16.0
Liberty (supercharged)	12	1,700	(3)	(3)	216	216	216	216	216	200	16.0
Packard	825	1,800	91	91	116	99	82	67	60	58	8.6
Packard	1237	1,800	138	138	175	150	123	102	90	87	13.0
Packard	2025	1,800	230	230	292	250	205	169	150	145	21.6
Wright Hispano	I	1,450	70	70	89	76	63	52	46	44	6.2
Wright Hispano[4]	E-2	1,800	81	81	103	88	73	60	53	51	7.6
Wright Hispano[5]	E-2	2,000	89	89	113	97	80	66	58	56	8.4
Wright Hispano	H	1,800	142	142	180	154	127	104	93	90	12.4
Wright Hispano	H-3	2,000	149	149	189	162	133	110	97	94	14.0
Wright	Radial	1,800	158	158	200	171	141	116	103	99	24.5
Lawrance	3 cyl	1,600	23	23	29	25	20	17	15	14	3.5
Lawrance	R-1	1,600	63	63	80	68	56	46	41	40	9.8
Lawrance	J-1	1,800	90	90	114	98	80	66	59	57	14.0
Le Rhone	C	1,200	50	50	64	55	45	37	33	32	6.4
Le Rhone	J-b	1,200	76	76	96	82	68	56	49	48	9.6
Le Rhone	R	1,350	114	114	144	123	101	84	74	72	14.4
Curtiss	OX-5	1,400	39	39	49	42	34	28	25	24	3.6
Curtiss	C-6	1,750	68	68	86	74	61	50	44	43	6.4
Curtiss (direct)	C-12	2,000	160	160	203	173	143	118	104	101	15.0
Rausie	E-6	1,650	68	68	86	74	61	50	44	43	6.4
Aeromarine	U-8-D	1,600	72	72	92	79	65	53	47	46	6.8
Almen	Barrel	2,000	160	160	203	173	143	118	104	101	15.0
McCook	W-1	1,700	298	298	378	323	266	219	194	188	28.0
McCook	W-2	1,400	426	426	540	462	380	313	278	268	40.0

[1] The hourly fuel consumption for both normal and high compression ratios is assumed to be the same at a given speed, since no changes in carburetor setting are contemplated or are generally necessary. However, with the high ratios, "doped" fuel must be used.

[2] These data apply only to high compression engines which have to be throttled at sea level and up to 7,000 feet to avoid detonation. This fuel consumption is maintained to 7,000 feet. Above 7,000 feet, values are the same as for operation with doped fuel.

[3] The supercharged Liberty does not have to be run throttled, as explained in footnote 2.

[4] Training.

[5] Alert.

Table III.—*Per cent variation in horsepower with altitude at constant engine speed, for normal engines.*[1]

Altitude.	Per cent horsepower.
Sea level	100.0
5,000 feet	83.8
10,000 feet	68.0
15,000 feet	53.7
20,000 feet	40.3
25,000 feet	26.1

[1] Based on average results obtained in the altitude chamber of the Bureau of Standards, 1920, on the Liberty 12, Hispano-Suiza 300, and Hispano-Suiza 180 engines at several speeds. See Engineering Division Report, Serial No. 1232.

Table IV.—*Per cent drop with altitude in speed of engine-propeller unit in flight, for normal engines.*[1]

Altitude.	Per cent revolutions per minute.
Sea level	100.0
5,000 feet	98.5
10,000 feet	95.9
15,000 feet	93.4
20,000 feet	88.8
25,000 feet	83.4

[1] Based on data obtained in flight on eight Liberty 12, four Hispano-Suiza model "H," and one Hispano-Suiza model "E" engines.

Table V.—*Per cent variation in horsepower with altitude, allowing for drop in speed of the engine-propeller unit, for normal engines*[1]

Altitude.	Per cent horsepower.
Sea level	100.0
5,000 feet	82.5
10,000 feet	65.2
15,000 feet	50.2
20,000 feet	35.8
25,000 feet	21.8

[1] Based on values of Tables III and IV.

Table VI.—*Per cent variation in specific fuel consumption with altitude, for normal engines.*[1]

Altitude.	Per cent specific fuel consumption.
Sea level	100.0
5,000 feet	103.6
10,000 feet	108.0
15,000 feet	115.7
20,000 feet	144.1
25,000 feet	228.5

[1] Based on the results obtained in the Bureau of Standards altitude chamber on the model "H" Hispano-Suiza and the 12-cylinder Liberty engines, each operating at two speeds. See Engineering Division Reports, Serial Nos. 1232 and 1233.

Table VII.—*Per cent variation in hourly fuel consumption with altitude, allowing for drop in speed of the engine-propeller unit, for normal engines.*[1]

Altitude.	Per cent hourly fuel consumption.
Sea level	100.0
5,000 feet	85.5
10,000 feet	70.4
15,000 feet	58.0
20,000 feet	51.4
25,000 feet	49.7

[1] Based on Tables V and VI.

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AIR SERVICE INFORMATION CIRCULAR.

(AVIATION.)

CHANGES No. 3. — WAR DEPARTMENT, AIR SERVICE, *June 15, 1922.*

Page 5, Table II, sections A and B, and page 6, Table IIa, inclusive, Air Service Information Circular, Volume IV, No. 317, "Method for Estimating Power and Fuel Consumption of Normal Compression Aviation Engines in Flight at Various Altitudes," are changed, by direction of the Chief of Air Service, in accordance with a recommendation of the Engineering Division contained in a letter dated April 27, 1922, as follows:

Page 5, Table II, sections A and B, substitute the following:

TABLE II.—*Estimated full-throttle horsepower at actual revolutions per minute at sea level and various altitudes.*[1]

SECTION A.—NORMAL COMPRESSION RATIOS APPROXIMATELY 5-5.5:1.

Engine and class of service.	Model.	Normal revolutions per minute.	Total weight dry, pounds.	Horsepower at actual revolutions per minute.[2]					
				Sea level.	5,000 feet.	10,000 feet.	15,000 feet.	20,000 feet.	25,000 feet.
Training:									
Aeromarine	U-8-D	1,600	560	180	148	117	90	64	39
Curtiss	OX-5	1,400	385	90	74	59	45	32	20
Curtiss	C-6	1,750	450	160	132	104	80	57	35
Lawrance	J-1	[3] 435		180	148	117	90	64	39
Le Rhone	C	1,200	260	[4] 80	66	52	40	29	17
Le Rhone	J-b	1,200	320	[4] 120	99	78	60	43	26
Liberty [5]	"6"	1,700	635	200	165	130	100	72	44
Packard	825	1,450	555	180	148	117	90	64	39
Rausie	E-6	1,650	550	160	132	104	80	57	35
Wright Hispano	E-2	1,700	475	180	148	117	90	64	39
Wright Hispano	I	1,700	470	180	148	117	90	64	39
Alert:									
Aeromarine	U-8-D	2,000	560	200	165	130	100	72	44
Lawrance	J-1	1,800	[3] 435	[3] 200	165	130	100	72	44
Le Rhone	R	1,350	380	160	132	104	80	57	35
Packard	825	2,000	555	225	186	147	113	81	49
Wright Hispano	E-2	2,000	475	210	173	137	105	75	46
Pursuit:									
Almen	Barrel	2,000	725	[3] 375	309	245	188	134	82
Curtiss	CD-12	2,000	705	375	309	245	188	134	82
Packard	1237	1,800	740	[6] 325	268	212	163	116	71
Wright Hispano	H	1,800	635	310	256	202	156	111	68
Wright Hispano	H-3	1,800	620	315	260	205	158	113	69
Wright Hispano	H-3	2,000	620	350	289	228	176	125	76
Wright	Radial	1,650	[3] 885	[3] 350	289	228	176	125	76
Observation and bombardment:									
Liberty	"12"	1,700	[7] 845	400	330	261	201	143	87
Liberty [8]	"12"	1,700	1,010	400	400	400	400	400	333
McCook	W-1	1,700	1,815	700	578	456	351	250	153
McCook	W-2	1,400	[3] 2,400	[3] 1,000	825	652	502	358	218
Packard	2025	1,800	1,170	540	446	352	271	193	118
Miscellaneous:									
Lawrance	"L" series	1,700	160	55	45	36	28	20	12
Lawrance	Torpedo	1,800	155	55	45	36	28	20	12

[1] Add 10 per cent to power output in making computations for cooling systems. The performance estimates are based on actual tests except in instances where reference is made to footnotes 3 and 4. In most cases, the estimates are lower than the test results to allow for variation between engines, atmospheric variations, etc.
[2] Allowing for drop in engine propeller speed based on average drop observed on numerous tests of Liberty and Wright Hispano engines.
[3] Estimated. (Engines under construction; in most cases no test data or weights are available.)
[4] Rated power. Actual developed power not known.
[5] Equipped with magneto ignition.
[6] Power output obtained from report by Packard Motor Car Co. No engines of this type (with low compression) are planned for production.
[7] Weight is with Zenith U. S. 52 carburetors. With inverted carburetors weight is 860 pounds.
[8] Equipped with General Electric supercharger. Power output assumed constant to 20,000 feet and then to decrease with decrease in density.

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CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

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Table II.—*Estimated full-throttle horsepower at actual revolutions per minute at sea level and various altitudes*—Con.

SECTION B.—HIGH COMPRESSION RATIO OF 6½:1.

Engine and class of service.	Model.	Normal revolutions per minute.	Total weight dry, pounds.	Horsepower unblended gasoline.		Horsepower with doped fuel.[9]					
				Sea level.	5,000 feet.[10]	Sea level.	5,000 feet.	10,000 feet.	15,000 feet.	20,000 feet.	25,000 feet.
Training:											
Aeromarine	U-8-D	1,600	560	147	147	195	161	127	98	70	43
Curtiss	C-6	1,750	450	132	132	175	144	114	88	63	38
Lawrance	J-1	1,650	[11] 435	147	147	195	161	127	98	70	43
Liberty	"6"	1,700	635	162	162	215	177	140	108	77	47
Packard	825	1,450	555	147	147	195	161	127	98	70	43
Wright Hispano	E-2	1,700	475	147	147	195	161	127	98	70	43
Alert:											
Aeromarine	U-8-D	2,000	560	162	162	215	177	140	108	77	47
Lawrance	J-1	1,800	[11] 435	162	162	215	177	140	108	77	47
Packard	825	2,000	555	180	180	240	198	157	121	86	52
Wright-Hispano	E-2	2,000	475	169	169	225	186	147	113	81	49
Pursuit:											
Almen	Barrel	2,000	725	305	305	405	334	264	203	145	88
Curtiss	CD-12	2,000	705	305	305	405	334	264	203	145	88
Packard	1237	1,800	740	263	263	350	289	228	176	125	76
Wright Hispano [12]	H-3	1,800	620	256	256	340	280	221	171	122	74
Wright Hispano [12]	H-3	2,000	620	282	282	375	309	245	188	134	82
Wright	Radial	1,650	[11] 885	286	286	380	313	248	191	136	83
Observation and bombardment:											
Liberty [12]	"12"	1,700	815	338	338	450	371	294	226	161	98
McCook	W-1	1,700	1,815	568	568	755	623	492	379	270	165
McCook	W-2	1,400	[11] 2,400	812	812	1,080	891	704	542	387	235
Packard	2025	1,800	1,170	440	440	585	483	381	294	209	128

[9] Allowing for drop in engine-propeller speed based on average drop observed on numerous tests of Liberty and Wright Hispano engines with normal compression ratios. While tests show that the drop is not quite as great for the high compression ratio, the absolute difference is small enough to be disregarded for the sake of simplicity.

[10] This horsepower is maintained (by throttling) to 7,000 feet. Above 7,000 feet values are the same as for operation with doped fuel.

[11] Estimated.

[12] Increase of sea-level horsepower with 6½:1 compression ratio obtained from actual tests of high compression engines compared with output with 5–5½:1 compression ratios. For the other engines the sea-level horsepower (using doped fuel) was estimated to be 8 per cent greater than the sea-level horsepower with 5–5½:1 compression ratios.

(C. A. S. I. C. 3)

Page 6, Table IIa, substitute the following:

Table IIa.—*Estimated full-throttle fuel and oil consumption in pounds per hour at sea level and various altitudes for both normal and high compression ratios.*[1]

Engine and class of service.	Model.	Normal revolutions per minute.	Fuel consumption, unblended gasoline.[2]		Hourly fuel consumption in pounds.[1]						Oil consumed, pounds per hour.
			Sea level.	5,000 feet.	Sea level.	5,000 feet.	10,000 feet.	15,000 feet.	20,000 feet.	25,000 feet.	
Training:											
Aeromarine	U-8-D	1,600	76	76	97	83	68	56	50	48	7.2
Curtiss	OX-5	1,400	(3)	(3)	49	42	34	28	25	24	3.6
Curtiss	C-6	1,750	68	68	86	74	61	50	44	43	6.4
Lawrance	J-1	1,650	81	81	103	88	73	60	53	51	10.8
Le Rhone	C	1,200	(3)	(3)	64	55	45	37	33	32	6.4
Le Rhone	J-b	1,200	(3)	(3)	96	82	68	56	49	48	9.6
Liberty	"6"	1,700	85	85	108	92	76	63	56	54	8.0
Packard	825	1,450	76	76	97	83	68	56	50	48	7.2
Rausie	E-6	1,650	(3)	(3)	86	74	61	50	44	43	6.4
Wright Hispano	E-2	1,700	76	76	97	83	68	56	50	48	7.2
Wright Hispano	I	1,700	(3)	(3)	97	83	68	56	50	48	7.2
Alert:											
Aeromarine	U-8-D	2,000	85	85	108	92	76	63	56	54	8.0
Lawrance	J-1	1,800	90	90	114	98	80	66	59	57	12.0
Le Rhone	R	1,350	(3)	(3)	128	109	90	74	66	64	12.8
Packard	825	2,000	96	96	122	104	86	71	63	61	9.0
Wright Hispano	E-2	2,000	89	89	113	97	80	66	58	56	8.4
Pursuit:											
Almen	Barrel	2,000	160	160	203	173	143	118	104	101	22.5
Curtiss	CD-12	2,000	160	160	203	173	143	118	104	101	15.0
Packard	1237	1,800	138	138	175	150	123	102	90	87	13.0
Wright Hispano	H	1,800	(3)	(3)	167	143	118	97	86	83	12.4
Wright Hispano	H-3	1,800	134	134	170	145	120	99	87	84	12.6
Wright Hispano	H-3	2,000	149	149	189	162	133	110	97	94	14.0
Wright	Radial	1,650	158	158	200	171	141	116	103	99	21.0
Observation and bombardment:											
Liberty	"12"	1,700	170	170	216	185	152	125	111	107	16.0
Liberty (supercharged)	"12"	1,700	(4)	(4)	216	216	216	216	216	200	16.0
McCook	W-1	1,700	298	298	378	323	266	219	194	188	28.0
McCook	W-2	1,400	426	426	540	462	380	313	278	268	40.0
Packard	2025	1,800	230	230	292	250	205	169	150	145	21.6
Miscellaneous:											
Lawrance	"L" Series	1,700	(3)	(3)	31	27	22	18	16	15	3.3
Lawrance	Torpedo	1,800	(3)	(3)	31	27	22	18	16	15	3.3

[1] These data apply only to high-compression engines which have to be throttled at sea level and up to 7,000 feet to avoid detonation. This fuel consumption is maintained to 7,000 feet. Above 7,000 feet, values are the same as for operation with doped fuel.

[2] The hourly fuel consumption for both normal and high-compression ratios is assumed to be the same at a given speed, since no changes in carburetor setting are contemplated or are generally necessary. However, with the high ratios "doped" fuel must be used.

[3] These engines will not be equipped with high-compression pistons, and consequently these data are omitted.

[4] The supercharged Liberty does not have to be run throttled, as explained in footnote 3.

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